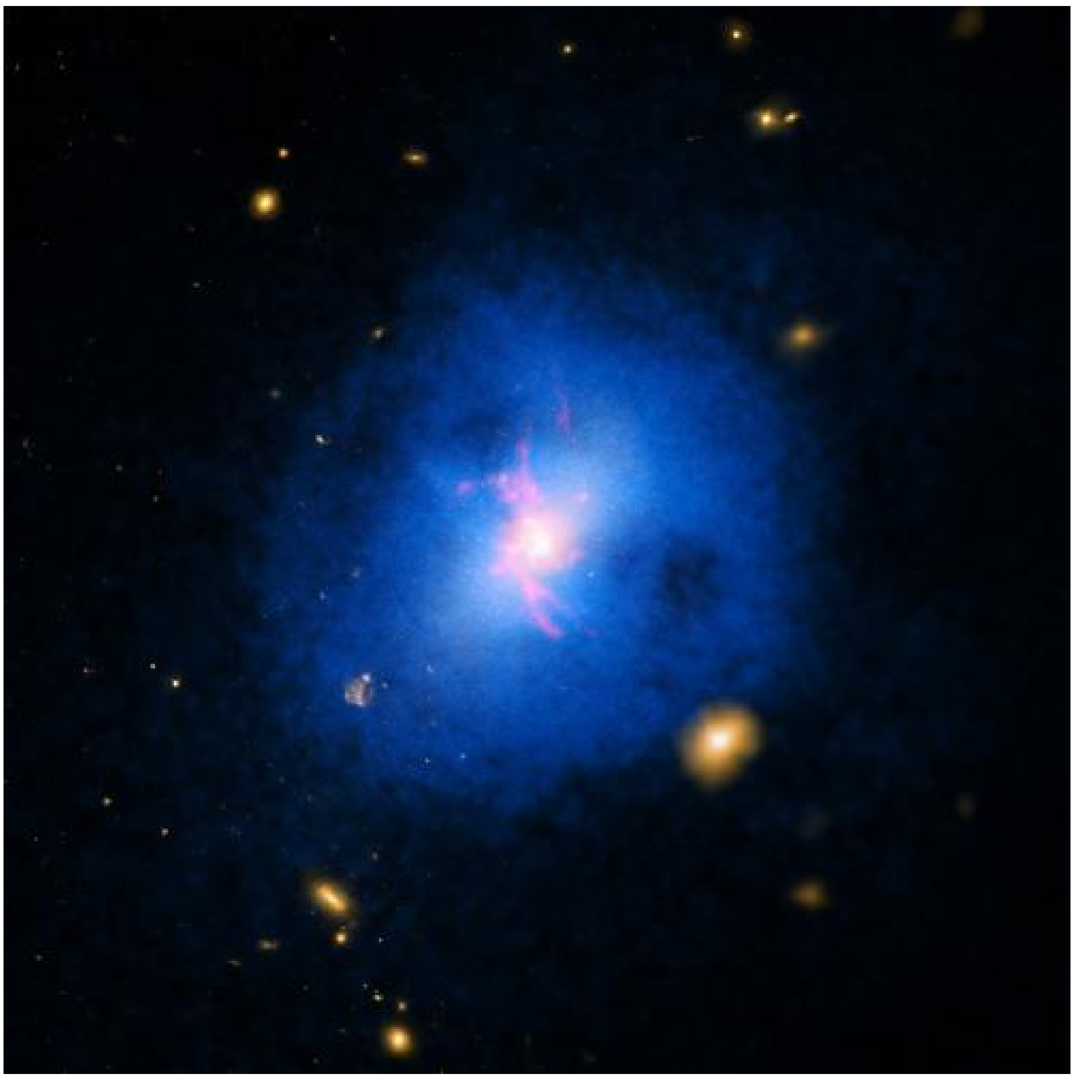
PHYS.ORG

Study explains why galaxies don't churn out as many stars as they should

March 4 2015



A galaxy cluster known as Abell 2597 was one of about 200 that were studied by a team of astronomers trying to determine why some galaxies are more prolific at making new stars than others. Led by MSU, the study found that galactic “precipitation,” actually cooling gases, and its relationship to the black holes at the centers of the clusters, contribute to the regulation of star formation. The research is published in the journal *Nature*. Credit: NASA/CXC/STSci/DSS/Magellan.

A handful of new stars are born each year in the Milky Way, while many more blink on across the universe. But astronomers have observed that galaxies should be churning out millions more stars, based on the amount of interstellar gas available.

Now researchers from MIT and Michigan State University have pieced together a theory describing how clusters of galaxies may regulate star formation. They describe their framework this week in the journal *Nature*.

When intracluster gas cools rapidly, it condenses, then collapses to form new stars. Scientists have long thought that something must be keeping the gas from cooling enough to generate more stars—but exactly what has remained a mystery.

For some galaxy clusters, the researchers say, the intracluster gas may simply be too hot—on the order of hundreds of millions of degrees Celsius. Even if one region experiences some cooling, the intensity of the surrounding heat would keep that region from cooling further—an effect known as conduction.

"It would be like putting an ice cube in a boiling pot of water—the average temperature is pretty much still boiling," says Michael McDonald, a Hubble Fellow in MIT's Kavli Institute for Astrophysics and Space Research. "At super-high temperatures, conduction smooths out the temperature distribution so you don't get any of these cold clouds that should form stars."

For so-called "cool core" galaxy clusters, the gas near the center may be cool enough to form some stars. However, a portion of this cooled gas may rain down into a central black hole, which then spews out hot material that serves to reheat the surroundings, preventing many stars from forming—an effect the team terms "precipitation-driven feedback."

"Some stars will form, but before it gets too out of hand, the black hole will heat everything back up—it's like a thermostat for the cluster," McDonald says. "The combination of conduction and precipitation-driven feedback provides a simple, clear picture of how star formation is governed in galaxy clusters."

Crossing a galactic threshold

Throughout the universe, there exist two main classes of galaxy clusters: cool core clusters—those that are rapidly cooling and forming stars—and non-cool core clusters—those have not had sufficient time to cool.

The Coma cluster, a non-cool cluster, is filled with gas at a scorching 100 million degrees Celsius. To form any stars, this gas would have to cool for several billion years. In contrast, the nearby Perseus cluster is a cool core cluster whose intracluster gas is a relatively mild several million degrees Celsius. New stars occasionally emerge from the cooling of this gas in the Perseus cluster, though not as many as scientists would predict.

"The amount of fuel for star formation outpaces the amount of stars 10 times, so these clusters should be really star-rich," McDonald says. "You really need some mechanism to prevent gas from cooling, otherwise the universe would have 10 times as many stars."

McDonald and his colleagues worked out a theoretical framework that relies on two anti-cooling mechanisms.

The group calculated the behavior of intracluster gas based on a galaxy cluster's radius, mass, density, and temperature. The researchers found that there is a critical temperature threshold below which the cooling of gas accelerates significantly, causing gas to cool rapidly enough to form stars.

According to the group's theory, two different mechanisms regulate star formation, depending on whether a galaxy cluster is above or below the temperature threshold. For clusters that are significantly above the threshold, conduction puts a damper on star formation: The surrounding hot gas overwhelms any pockets of cold gas that may form, keeping everything in the cluster at high temperatures.

"For these hotter clusters, they're stuck in this hot state, and will never cool and form stars," McDonald says. "Once you get into this very high-temperature regime, cooling is really inefficient, and they're stuck there forever."

For gas at temperatures closer to the lower threshold, it's much easier to cool to form stars. However, in these clusters, precipitation-driven feedback starts to kick in to regulate star formation: While cooling gas can quickly condense into clouds of droplets that can form stars, these droplets can also rain down into a central black hole—in which case the black hole may emit hot jets of material back into the cluster, heating the surrounding gas back up to prevent further stars from forming.

"In the Perseus cluster, we see these jets acting on hot gas, with all these bubbles and ripples and shockwaves," McDonald says. "Now we have a good sense of what triggered those jets, which was precipitating gas falling onto the black hole."

On track

McDonald and his colleagues compared their theoretical framework to observations of distant galaxy clusters, and found that their theory matched the observed differences between clusters. The team collected data from the Chandra X-ray Observatory and the South Pole Telescope—an observatory in Antarctica that searches for far-off massive galaxy clusters.

The researchers compared their theoretical framework with the gas cooling times of every known galaxy cluster, and found that clusters filtered into two populations—very slowly cooling clusters, and clusters that are cooling rapidly, closer to the rate predicted by the group as a critical threshold.

By using the theoretical framework, McDonald says researchers may be able to predict the evolution of galaxy clusters, and the stars they produce.

"We've built a track that clusters follow," McDonald says. "The nice, simple thing about this framework is that you're stuck in one of two modes, for a very long time, until something very catastrophic bumps you out, like a head-on collision with another cluster."

The researchers hope to look deeper into the theory to see whether the mechanisms regulating star formation in clusters also apply to individual galaxies. Preliminary evidence, he says, suggests that is the case.

"If we can use all this information to understand why or why not stars form around us, then we've made a big step forward," McDonald says.

More information: Regulation of star formation in giant galaxies by precipitation, feedback, and conduction, *Nature*, 2015.

dx.doi.org/10.1038/nature14167

Provided by Massachusetts Institute of Technology